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Maximising the co-benefits of light-duty dieselisation in Asia

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[a] Abstract

Diesel passenger vehicles are rapidly gaining market share in developing Asia primarily due to reduced fuel costs. As dieselisation proceeds, however, policy frameworks common to that region fail to capture the full economic, climate and energy security benefits of this phenomenon. In this chapter, we evaluate how the design of vehicle emission standards, fuel efficiency standards and fuel tax policy can undermine the public health, economic and climate benefits of dieselisation. We propose a new policy framework that more fully captures these.

We first highlight the likely adverse impacts of lax diesel emission controls. We then analyse the CO_2 equivalent reduction potential of Euro 3 and Euro 4 compliant light-duty diesels compared to light-duty petrol and find this is reduced by 80 percent (range 30 to 160) when properly accounting for heat absorbing aerosol emissions like black carbon. We also show that an additional 15 to 75 percent of potential CO_2 emission reductions can be lost under weight-based fuel efficiency standards due to endogenous weight increases. We then estimate the economic cost of tax policies and subsidies as a consequence of dieselisation. In light of these outcomes, we propose an integrated, fuel neutral policy approach – a single set of emission standards for petrol and diesel-powered vehicles; corporate average or footprint-based efficiency standards; and fuel taxes levied based upon carbon content – to maximise the benefits of light-duty dieselisation.

[a] Introduction

Wildly fluctuating petroleum prices along with concerns about global climate change and domestic energy security are pushing many governments in Asia to expand the use of diesel engines in the light-duty fleet. Due to their greater efficiency relative to petrol engines (on the order of 30% on fuel economy basis and 15% on an

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energy equivalent basis), diesel-powered internal combustion engines can be an important tool to reduce the carbon dioxide (CO_2) emissions and fuel consumption of light-duty vehicles (Kasseris and Heywood, 2006; Transportation Efficiency Subgroup 2007).

There is increasing use of diesel engines in passenger vehicles. In the EU, diesels account for more than half of new vehicle sales. In India they constitute 30% of current sales and are on an upward trend to reach half of sales in 2010 (Reuters 2007, Centre for Science and Environment, undated). This has led transportation experts to coin the phrase "dieselisation". There are a number of drivers of this trend. Diesel vehicles are attractive to budget-conscious drivers, particularly when diesel fuel prices are held artificially low, as is the case in Europe and much of Asia. Concerns about CO_2 emissions may also be a factor. Advances in diesel technology, notably "common rail" fuel injection systems and technologies for NOx and PM after-treatment, have likewise alleviated many consumer and regulator concerns about diesel performance and emissions. Finally, light-duty diesels can offer a relatively low-cost, proven way for manufacturers to comply with fuel efficiency standards such as those in effect in China, Korea and Japan and under consideration in India today.

Unfortunately, existing policies in rapidly developing Asian nations – weak emission and fuel quality standards, weight-based fuel efficiency targets and the subsidisation of diesel fuel – pose a serious barrier to capturing the full climate and development benefits, or co-benefits, of light-duty dieselisation. In many cases, these policies are a continuation of the lenient treatment afforded diesel engines used in off-road and heavy-duty applications, including agriculture, fishing, construction, public transportation and trucking, that are viewed as important to the early stages of economic development. Typically, these policies include relaxed (or even non-existent) emission standards and the subsidisation of diesel fuel relative to petrol.

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Weak emission standards allow diesel cars and trucks to emit disproportionate levels of particulate matter (PM) and nitrogen oxides (NOx), which subsequently impact local air quality and exert regional and global climate effects. Diesel engines can also degrade the effectiveness of weight-based fuel efficiency targets. Since diesel vehicles are heavier than petrol vehicles, and since heavier vehicles are subject to less rigourous standards under weight-based fuel efficiency targets, dieselisation may compromise the effectiveness of passenger vehicle standards set as a function of weight. Finally, a shift to light-duty diesels can cause a significant drop in fuel tax revenues as consumers shift away from petrol to diesel, which is typically subsidised in Asian countries. Taken in sum, the limitations of current policies point to the need for an integrated emissions control strategy capable of maximising dieselisation co-benefits, a task we take on here.

The structure of this chapter is as follows begins first with a theoretical framework by which to understand co-benefits, and potential barriers to co-benefits, associated with light-duty dieselisation. We then analyse four ways that, lacking an integrated policy framework, the increased use of light-duty diesels can lead to sub-optimal climate and development outcomes: first, by exacerbating local air pollution and other adverse outcomes; second, by increasing emissions of climate-warming black carbon; third, by undermining the stringency of weight-based fuel efficiency standards; and fourth, by reducing fuel tax revenues. We conclude with an outline of three core principles of an integrated emissions control policy capable of maximising the co-benefits of light-duty dieselisation – fuel neutral emission standards; efficiency standards set as either a single corporate average or based upon vehicle size; and the taxation of transport fuels by carbon content.

While of theoretical interest, a closer look at co-benefits and dieselisation is needed to avoid policy mistakes that further limit the climate benefits of dieselisation. In at least two instances, the failure to proactively adopt policies to manage the

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drawbacks of light-duty diesels has undermined consumer demand: in Brazil, diesel subsidies precipitated a ban on diesel passenger vehicles, and in Japan, public anger in 1999 about the central government's inability to curb diesel pollution led to a successful campaign by local governments against diesel passenger vehicles (Rutherford 2006).

[a] Theoretical framework for co-benefits

While valuable, the fuel efficiency and cost savings of light-duty diesels can be offset to a large degree by troubling dis-benefits. Policy makers can expect increases in conventional pollutants and (perhaps counter intuitively) climate impacts should the lenient regulatory treatment offered diesels in non-road and heavy-duty applications be applied to the light-duty sector. An improved understanding of actions and policies that produce multiple benefits - or co-benefits – can help better capture the benefits of light-duty dieselisation and avoid unwelcome health, economic and climate trade offs. This is true for countries where dieselisation is well advanced such as India[1] and for countries that have yet to undergo dieselisation, such as China, where less than 1% of passenger vehicle sales today are diesels (China Business 2008).

Recent work emphasising the urgent need to slow anthropogenic climate change has led to greater interest in identifying single policies or strategies that can produce greenhouse gas reductions more rapidly by pursuing co-benefits. This body of literature assumes that single actions are more likely to succeed than multiple actions; that the pursuit of non-climate benefits will engage developing nations potentially responsible for the majority of future emissions growth; and that unnecessary trade offs between climate and other areas can be avoided. Co-benefits capture synergies between the interests of developed and developing nations, in theory producing beneficial outcomes more rapidly for both.

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The 2001 Bellagio Memorandum on Motor Vehicle Policy (Energy Foundation 2001) sets forth principles that incorporate a co-benefits approach to vehicle emissions regulation. It distils the consensus view of an international body of transportation regulators and experts from the world's major vehicle and fuel markets on a best practices approach to vehicle regulation, and led to the foundation of the International Council on Clean Transportation (ICCT). The principles that incorporate the concept of co-benefits include the following:
[bl]

** New vehicle standards for greenhouse gas emissions and conventional pollutants should be fuel neutral;
** Clean vehicle strategies should promote air quality (including air toxins) and greenhouse gas goals in parallel.

Several additional principles highlight ways to maximise the reduction potential of regulatory instruments and best approaches for incorporating fiscal policy into vehicle regulation. They include the following:
[bl]

** Measures should be designed to avoid promoting increases in the size, weight or power of vehicles;
** Vehicles that perform the same function should be required to meet the same standards, based on the capability of the leader, not the laggard; and
** Future new vehicle standards should be fuel neutral.
** Economic instruments should be used to promote clean, efficient vehicles and fuels;
** Cost-effectiveness should be considered in achieving goals; and;

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** Measures to reduce greenhouse gas emissions from vehicles could include fiscal incentives.

In this chapter, we consider the trade offs or dis-benefits that can result from light-duty dieselisation under a policy regime that disregards these international best practices. First, we survey the public health, climate and developmental dis-benefits of weak emission controls on light-duty diesels. Second, we reassess the climate benefits of light-duty diesels after 1) accounting for the warming influence of black carbon aerosols; and 2) the tendency of diesel passenger vehicles to undermine the stringency of fuel efficiency standard set according to vehicle weight. Third, we consider the impact of dieselisation on fuel tax revenues in developing Asia, where diesel fuel is typically subsidised relative to petrol.

[a] Dis-benefits of light-duty dieselisation

[b] Adverse public health impacts

Uncontrolled or under-controlled light-duty diesels emit high levels of nitrogen oxides and particulate matter: as a result, poorly planned dieselisation can have significant public health impacts. National emission standards have typically allowed greater levels of pollution to be emitted from cars and trucks operating with diesel rather than petrol engines. For example, India's national emission standards in 2005, patterned on Europe's Euro 2 standards, allows for between 40 and 70% more NOx to be emitted from light-duty diesels than petrol equivalents on a standardised test cycle (Dieselnet 2004).

Developing Asia already bears a disproportionate burden of mortality and disease from air pollution. According to the World Health Organisation approximately two-thirds of the 800,000 annual deaths and 4.6 million years of life lost from urban air pollution are lost in developing Asia (Cohen et al, 2004). PM

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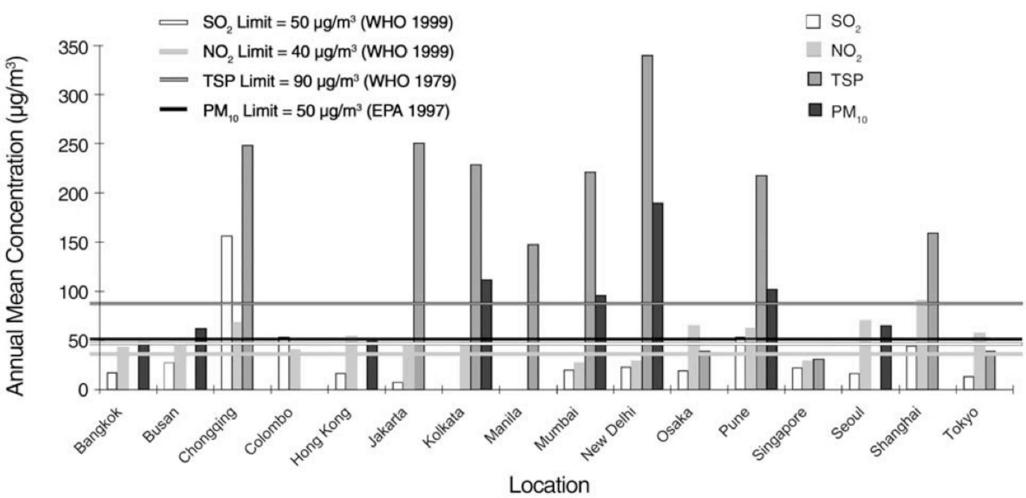
emissions are associated with cardiopulmonary and respiratory-related mortality, increased hospital admissions, bronchitis, asthma attacks and restricted activity days (Kunzli et al 2000). Figure 1 shows the annual mean concentration of major air pollutants in Asian mega cities and how this compares to recommended standards. In 2004 the concentration of PM10 (particulate matter with an aerodynamic diameter smaller than 10 micrometers) in a number of these mega cities exceeded EPA and WHO guidelines.

Figure 1. *Annual mean concentration of select air pollutants in cities of developing Asia*



Source: Health Effects Institute, 2004

The association between increased particulate matter emissions (typically, as measured through PM10) and mortality has been well established. For example, several comprehensive studies of cities in North America and Western Europe have found an associated risk of all-cause mortality and air pollution between 0.2 (range 0.1 to 0.4) and 0.6 (range 0.4 to 0.7) percent for every 10 μg/m³ increase in ambient PM10 (Dominici et al, 2003; Katsouyanni et al, 2003). A global 75-city study found an association of 0.6 percent (range 0.5 to 0.7) (Anderson et al 2005).

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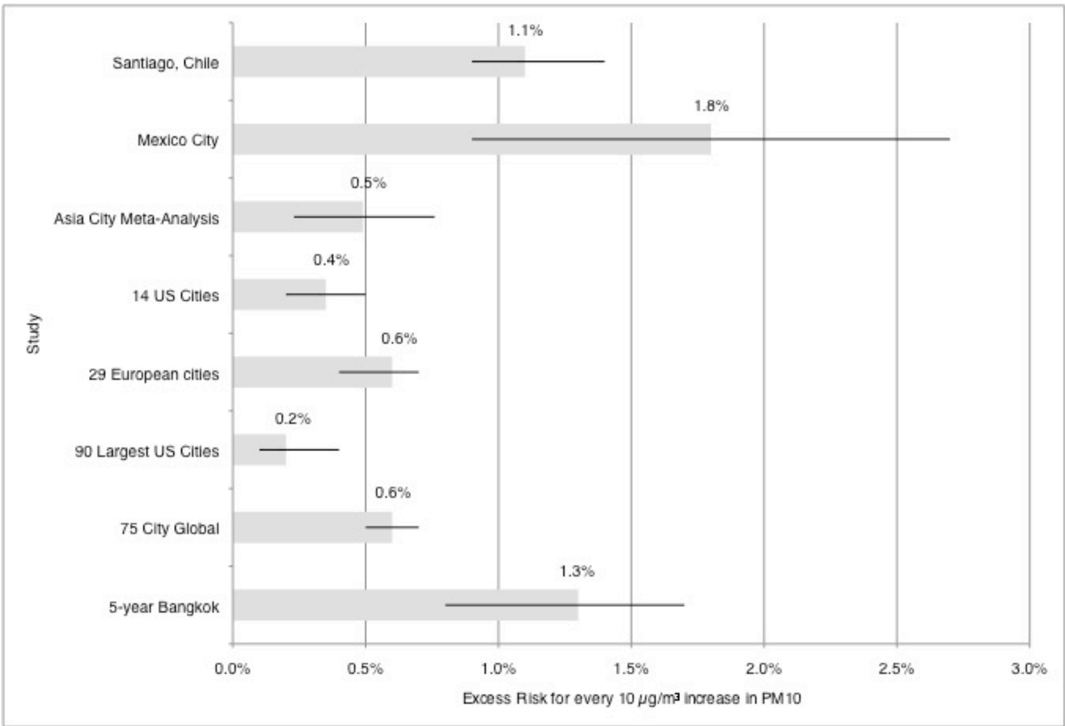
Until recently there were few reviews of excess risk specific to Asia. In 2004 the Health Effects Institute (HEI) as part of its Public Health and Air Pollution in Asia (PAPA) project, released an important survey of air pollution and health studies for the region (Health Effects Institute, 2004). Figure 2 compares the results of this study to other similar studies. It included an Asian city meta-analysis that found an excess risk of 0.49 (range 0.23 to 0.76) percent for every 10 μg/m^3 increase in PM10 concentrations. In Inchon, South Korea the effect estimate is 0.8 (range 0.2 to 1.6) (Hong et al, 1999). In 2008 a four-city study of Asia (Wong et al, 2008) found an excess mortality risk between 0.26 (range 0.14 to 0.37) and 1.25 (range 0.82 to 1.69) percent, with Wuhan, China ranking the lowest and Bangkok, Thailand the highest. The level observed for Bangkok was higher than observations from Santiago, Chile of 1.1 (range 0.9 to 1.4)] and nearly as high as Mexico City estimated at 1.8 (range 0.9 to 2.7) (Ostro et al 1996; Castillejos et al, 2000), ranking the residents of Bangkok among the most vulnerable to air pollution worldwide.

Figure 2. *Associations of PM10 and mortality*



Source: Ostro et al, 1996; Castillejos et al, 2000; Health Effects Institute, 2004; Dominici et al, 2003; Katsouyanni et al, 2003; Anderson et al, 2005

The PAPA multi-city study observed that the health effects of air pollution in Asian cities are similar or greater than the effects in North American and Western European cities. Since Asian residents tend to spend more time outdoors and less time in places with air conditioning, they are more exposed to air pollution than residents of cities in the United States and the European Union. Lower socioeconomic status and higher pollution peaks, such as those experienced at roadsides, are also factors.

Table 1 summarises the burden of disease due to air pollution in developing Asia. Major cities in China and India face serious air pollution problems (HEI 2004). Mean levels of total suspended particulate matter (TSP) and PM10 in Beijing remained constant between 1999 and 2002 at 370 $\mu g/m^3$ and 160 $\mu g/m^3$ for each pollutant, respectively. Increasing numbers of vehicles and transportation infrastructure have kept NO2, a precursor of ozone, at a high level of 75 $\mu g/m^3$. Vehicle emission controls and scrappage programs will reduce these emissions, but these will be offset somewhat by growth in the vehicle population. Delhi, India is one of the world's most polluted cities. Major emission sources include motor vehicles, industrial activity, coal use, refuse burning and domestic heating and cooking. Annual mean levels of TSP remained stable for the ten-year period between 1991 and 2001 at about 360 $\mu g/m^3$ in residential areas. A time-series study for India estimated a 2.3% decrease in deaths for a 100 $\mu g/m^3$ decrease in TSP (Cropper et al, 1997). SO2 and NO2 levels have fallen generally within the guidelines of the World Health Organisation (WHO). Recent actions to control vehicle emissions, improve fuel quality, scrap old vehicles and reduce industrial emissions have produced declines in urban pollution, however particulate matter emissions have remained high.

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Table 1. *Estimated burden of disease due to air pollution in developing Asia*

	East Asia	Southeast Asia	South Asia	Asian Total
Population (millions)	1533	294	1242	3069
Percent in rural areas	65%	64%	72%	68%
Estimated urban mean PM2.5 concentration	42	47	38	41
Urban outdoor air pollution				
Deaths (thousands)	355	32	132	519
% Total DALYs	1.4%	0.6%	0.4%	0.8%
Total air pollution				
Deaths (thousands)	1065	91	758	1934
% Total DALYs	5.9%	3.7%	5.4%	5.4%

Source: Health Effects Institute, 2004. Adapted from sidebar 3, p41

Diesels emit a type of particulate matter that is uniquely toxic. It contains a mixture of solid and liquid particles such as carbon, hydrocarbons and inorganic material that can be particularly harmful to human health. In 1998 the State of California classified diesel particulate matter as a toxic air contaminant for its strong potential to cause premature death, cancer and other health problems. A strategy focused on diesel emissions would capture some of these very negative health impacts.

[b] Adverse economic impacts

These public health impacts have large macroeconomic impacts. Several studies in developing Asia have estimated the cost of air pollution attributable to morbidity and mortality. For three Chinese localities - Shanghai, Shanxi province and Beijing - the health cost of PM10 ranged from 1.0 to 6.6 percent of GDP (see Table

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2). A study of China as a whole showed that during the period 2000 to 2004 the health cost of air pollution ranged from 0.4 to 1.3 percent of GDP.

Table 2. *Cost of air pollution as % of GDP*

Study	Location	Pollutant	Study Period	Cost as % GDP
Wan, Yang, and Masui (2005)	China	PM10	2000-2004	0.4%-1.3%
Kan & Chen (2004)	Shanghai, China	PM10	2001	1%
Cao (2004)	Shanxi, China	PM10, TSP	1999	1.90%
Zhang, Song and Cai (2007)	Beijing, China	PM10	2004	6.60%

Source: ICCT

Other studies have looked at the health cost of air pollution from the perspective of income loss. Srivastava and Kumar (2002) found that it would cost only 29 percent of the associated health damages to avoid morbidity and mortality from ambient air pollution in Mumbai, India. Parikh and Hadker (2003) found the average cost of the health effects of air pollution was 0.3 percent of income, however 5 percent of individuals with the most severe health impacts lost about 19 percent of their income. One forward looking study by Mead and Brajer (2006) found that if WHO standards were met in China between 2003 to 2012, the country could avoid morbidity-related costs equivalent to $40 billion USD and mortality-related costs of more than $200 billion USD.

On a positive note, research has shown that the net benefits of enforcing Euro 4 emission standards in petrol vehicles and Euro 5 standards in diesel vehicles, along with low sulphur fuel, could have very large benefits in China. Blumberg (2006) found that improved vehicle standards and cleaner fuels would produce a benefit-to-cost ratio of 20:1 and net benefits of $150 billion by the year 2030, while avoiding 1.5 million deaths, 110 million cases of bronchitis, 14 million cases of asthma and 990 million restricted activity days.

[b] Adverse climate impacts

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A growing body of evidence shows that black carbon, a sub-component of PM and a by-product of incomplete combustion, may play a large role in regional and global climate change. Transportation-related activities are responsible for 25 percent of global black carbon emissions (Bond, 2009). The trend in these emissions is downward as a consequence of tight emissions standards in North America and Europe (Walsh, 2009). However developing countries, particularly those in East and South Asia, will contribute the bulk of future transportation-related black carbon emissions growth.

According to the Intergovernmental Panel on Climate Change (IPCC), black carbon is at least the third largest contributor to positive radiative forcing since pre-industrial times (Forster et al, 2009, Table 2.13). New research suggests the IPCC underestimates its impact by nearly half, and if this is confirmed it would place black carbon into second place immediately after carbon dioxide (Ramanathan & Carmichael, 2008).

Studies suggest that black carbon emissions over Asia are contributing to regional shifts in precipitation and increases in the pace of melting from regional glaciers. Ramanathan et al (2005) modelled the regional climate effect of an Asian Brown Cloud (ABC) – a large mass of aerosols containing high concentrations of black carbon along with organic carbon, dust, sulphates and nitrates – over the Himalayan region. This study showed that ABC's over the South Asian region may have weakened monsoon rainfall by 5 percent between 1930 and 2000 and could increase the duration of drought from no more than 3 years per decade to periods consistently greater than 4 years per decade. Since food production and precipitation are closely linked, these regional climate effects could produce very large reductions in the availability of food and fresh water as drought trends and glacier melt persist.

There are strategic benefits to targeting black carbon emissions (ICCT, 2009). First, it is a very potent climate forcing agent. A pulse emission produces positive

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radiative forcing that is about 1600 times greater than carbon dioxide at the end of a 20-year period, so reducing one kilogram of black carbon can produce a much stronger benefit than reducing the same amount of carbon dioxide. Second, its short lifetime can produce rapid cooling in the future. Since black carbon lasts about one week in the atmosphere, these reductions can occur quickly and help to reduce future committed warming, which is not necessarily possible with a CO2-only strategy. Controlling these emissions can also delay and perhaps mitigate regional tipping points like the loss of Arctic summer sea ice and Asian glaciers. Finally, the technological approach - installation of a diesel particulate filter - produces immediate reductions greater than 95 percent. These are important strategic benefits.

[a] Reassessing the climate and economic benefits of dieselisation

[b] The net climate impact of diesel particulate filters

Diesel passenger vehicles emit about twenty percent less carbon dioxide per kilometre compared to petrol vehicles based on the the higher efficiency of diesel engines, and the balance between the slightly higher energy and carbon content of diesel fuel. The results from our analysis presented in Table 3 verify this assumption. But this benefit of diesels may be offset by the climate forcing of black carbon, which forms the majority of the mass of PM emissions from uncontrolled engines.

Diesel particulate filters are very effective at reducing black carbon emissions. Diesel vehicles without a particulate trap emit particulate matter containing a 70 percent share of black carbon (Office of Air Quality Planning and Standards 2008). But application of a particulate trap reduces this share to just 10 percent of the remaining PM (Ayala, A. 2008, pers. comm. 17 Oct). Diesel particulate traps are an important technological strategy for controlling not only the total mass of particulate matter, but also the black carbon fraction.

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We analyse the potential climate benefit of dieselisation in developing Asia via CO_2 and conventional pollutant emission test data from Europe, the world's most developed market for diesel passenger vehicles. Our analysis used passenger vehicle carbon dioxide and pollutant emissions (including particulate matter) published by the German Federal Motor Transport Authority (KBA-Kraftfahrt Bundesamt) in accordance with EC directive 2003/4/EC. KBA's 2007 publication contains 9637 type approval tests for passenger vehicle carbon dioxide emissions and 8707 tests for pollutant emissions including particulate matter, both tested under the European Test Cycle defined by EC-Directive 70/220/EEC and amended by 98/69/EC. The procedure accounts for filter regeneration by extending the cycle until a regenerating phase is completed and averaging the results.

From the KBA data we isolated the carbon dioxide and pollutant emission test data for equivalent models powered by both petrol and diesel engines.[2] Equivalent petrol and diesel models were identified by matching vehicle manufacturer or make; model; type code number; engine type; engine size; engine power; maximum speed; inertia mass; gears and transmission type; engine category; and technical features.

For each matched vehicle pair, we estimated a CO_2-equivalent emissions total as the sum of carbon dioxide emissions and carbon-equivalent particulate emissions. Particulate emissions were converted to carbon equivalent emissions by estimating a black carbon and organic carbon fraction for particulate matter and multiplying these by a global warming potential (GWP) estimated for 20 years. The 20-year GWP was chosen to reflect the preference for using short-lived forcing agents to achieve short-term policy targets. Particulate matter emissions from diesel vehicles without particulate traps were assumed to be 70 percent black carbon and 30 percent organic carbon (Office of Air Quality Planning and Standards 2008). Emissions from vehicles with traps were assumed to be 10 percent black carbon and 90 percent organic

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carbon (Ayala, A. 2008, pers. comm. 17 Oct). The 20-year GWP is an unofficial estimate drawn from data in the IPCC Fourth Assessment Report (Forster et al, 2007 Table 2.5). A full description of the methodology for their calculation is in International Council on Clean Transportation (2009).[3] A summary of the characteristics of each sample and results are provided in Table 3.

Table 3. *Net difference in CO2-equivalent (GWP20) emissions between diesel and petrol vehicles in the European light-duty fleet*

Count	Description	Petrol	Diesel	Absolute difference	Effect of diesel (%)
360	All matched pairs				
	Average fuel economy (g/km)	207	170	37	-18%
	Average particulate (g/km)	***	0.021	0.021	***
	CO2-eq (GWP20) emissions	**207**	**191**	**16**	**-8%**
264	Petrol matched against diesels without DPFs				
	Average fuel economy (g/km)	206	167	38	-19%
	Average particulate (g/km)	***	0.022	0.022	***
	CO2-eq (GWP20) emissions	**206**	**199**	**7**	**-3%**
171	Petrol matched against diesels with DPFs				
	Average fuel economy (g/km)	208	173	35	-17%
	Average particulate (g/km)	***	0.002	0.002	***
	CO2-eq (GWP20) emissions	**208**	**172**	**35**	**-17%**

Source: Kraftfahrt Bundesamt, 2007; ICCT analysis

Our results are consistent with the understanding that diesel engines offer an opportunity to significantly reduce CO_2 emissions from passenger vehicles. Relative to petrol models, diesel vehicles provided an 18 percent fuel economy benefit on average.[4]

Table 3 also shows that the climate benefit of light-duty diesels lacking particulate filters is reduced significantly when one properly accounts for the climate impact of black carbon emissions. The average particulate emissions from a diesel vehicle without a particulate filter were 0.022 g/km.[5] This means that light-duty diesels lacking a particulate filter only provide a 3 percent (range -14 to +12) CO2-

equivalent emissions benefit over petrol vehicles on a 20-year GWP basis.[6] After controlling for the efficiency penalty associated with the increased weight of diesel engines (see below), this means that the climate benefits of diesel vehicles lacking particulate filters are reduced by approximately 80 percent (range 30 to 160) by black carbon emissions. Note that since the vehicles tested under this program were Euro 3 or Euro 4 compliant, they are cleaner than many new vehicles sold in Asia today.[7] One therefore expects that even more of purported climate benefit of diesel passenger cars is lost there.

In contrast, a comparison of petrol vehicles to diesel vehicles with a particulate filter shows that the filter protects the climate benefits of fleet-wide dieselisation while dramatically reducing particulate pollution. On a 20-year basis, diesels with particulate filters reduced carbon-equivalent emissions by 17 percent over petrol vehicles, which was equal to their same performance on a fuel economy basis in this sample. We return to this point in Section 4.1.

[b] The emissions impact of fuel efficiency standard design

A second, less well-understood reason that light-duty diesels may under perform their climate potential is attributable to the interaction of dieselisation, vehicle mass and weight-based fuel efficiency standards. Diesel engines operate efficiently in part by achieving high compression ratios, which allow them to extract more useful energy per unit of fuel than petrol engines. Diesel engines must therefore be built solidly to sustain higher pressures, adding vehicle weight. Where governments impose efficiency targets on passenger vehicles as a function of weight, light-duty dieselisation results in less stringent standards. Manufacturers can then choose to redirect a portion of the inherent efficiency benefits of diesels to increased performance or vehicle size, in the process sacrificing some of the expected CO_2 benefits.

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For a first order approximation of how much of the efficiency benefit of light-duty diesels might be lost under weight-based standards in Asia, we again turn to the European example. We used a descriptive database of the complete 2006 EU15 light duty fleet and compacted this to 4,701 unique vehicle records. To capture identical vehicle models with a petrol and diesel engine, we matched pairs of petrol and diesel vehicles based on identical vehicle footprint and manufacturer group and extracted an average, sales-weighted curb weight and CO_2 emissions rate. The resulting CO_2 emissions rate of matched pairs showed high agreement with that of pairs isolated from the KBA dataset. Table 4 demonstrates the result of that analysis.

Table 4. *Weight and efficiency penalty with diesels*

Vehicle pop	Curb Weight (kg)				CO_2 Emissions (g/km)			
	Petrol	Diesel	Average	Δ(kg)	Petrol	Diesel	Total	Δ(%)
Matched Pairs only	1452	1500	1476	48	205	169	186	-18%
All vehicles	1203	1454	1333	250	166	157	161	-5%

Source: ICCT analysis

On average, the mass difference between matched diesel and petrol pairs, which serves as an approximation of the mass increase driven by shifting to a diesel engine without additional design changes, is 48 kg. Based upon a sales-weighted regression analysis of CO_2 emission versus curb weight, a 48 kg mass increase on a 1450 kg vehicle increases emissions by approximately 6 g/km, or 3.4%. In contrast, the sales-weighted mass difference between all petrol and diesel vehicles in the EU in 2006 was 250 kilograms, reflecting that fact that diesel engines are used preferentially in larger, upscale vehicles which can benefit more from their high torque.

The right-hand side of Table 4 shows how these mass differences translate into CO_2 emissions. Considering only matched pairs, the move from petrol to a diesel engine is associated with an 18% reduction in carbon dioxide emissions for functionally equivalent vehicles. Note that this reduction potential *includes* the fuel

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efficiency penalty associated with the greater engine weight of a diesel – we would expect a hypothetical diesel engine weighing no more than a petrol engine to offer a benefit of 21.4%. On a fleet wide basis, however, diesel vehicles on average emit only 9 grams less CO_2 per kilometre, a 5.4% reduction, than petrol vehicles because of the large mass differences between the average diesel and petrol vehicle.

The results outlined in Table 4 can be used to approximate the level of potential CO_2 reductions that might be sacrificed in developing Asian countries undergoing dieselisation and moving toward weight-based passenger vehicle efficiency standards such as those in effect in China and under consideration in India. The 48 kg and 250 kilograms mass differences above delineate a crude lower and upper bound for the mass changes one could expect if Asian countries followed the European dieselisation trend: 48 kilograms if an Asian manufacturer chooses to sell a functionally equivalent diesel vehicle in place of a petrol vehicle, while at most a 250 kg mass increase could result if an average petrol model is phased out in favour of a typical diesel model.

Under a hypothetical weight-based standard requiring equal percentage reductions from all vehicles, a baseline 21.4% fuel CO_2 reduction instead would result in an actual reduction of 5.4 to 18%, depending on the degree of upsizing that accompanies dieselisation. Thus, 15 to 75% of the CO_2 reduction potential of the light-duty diesel can be lost to weight increases, with the actual value on the low end if automakers do not dramatically improve the performance of or add many additional amenities to the new diesel model. We return to this finding in Section 4.2, which suggests alternate regulatory designs to guarantee that the efficiency benefits of diesels are devoted to CO_2 emissions reductions rather than to performance or size increases.

[b] Potential losses in tax revenue

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Poorly planned dieselisation also threatens economic development by reducing tax revenues as consumers shift from using petrol to diesel in passenger vehicles. Fuel taxes serve as an important source of funds for road construction and maintenance and, to a lesser degree, as a general revenue source for meeting developmental goals. Light-duty dieselisation will reduce tax revenue for two reasons: first, because diesel fuel tends to be subsidised in developing Asia, while petrol is taxed; second, because the higher efficiency of diesel engines reduces overall fuel consumption, leading to lower sales on a volume basis.

Figure 3 shows differences in the subsidisation and taxation for petrol and diesel in select Asian countries, as compiled by a worldwide survey of GTZ. Figure 4 provides an estimate of potential revenue losses associated with European-style light-duty dieselisation. On average, in 2006 governments in Asia tended to subsidise diesel fuel on the order of several US cents per litre, while petrol taxes averaged perhaps 15 to 20 cents per litre, with significant variation between countries. Accordingly, displacing a litre of petrol sales with a litre of diesel fuel for use in passenger vehicles leads to a loss in tax revenue on the order of 20 US cents per litre. Combined with the anticipated reduction of overall fuel use due to efficiency improvements, the widespread introduction of diesel passenger vehicles can be expected to lead significant losses in tax revenue for most of developing Asia should the current structure of taxes and subsidies remain in place.

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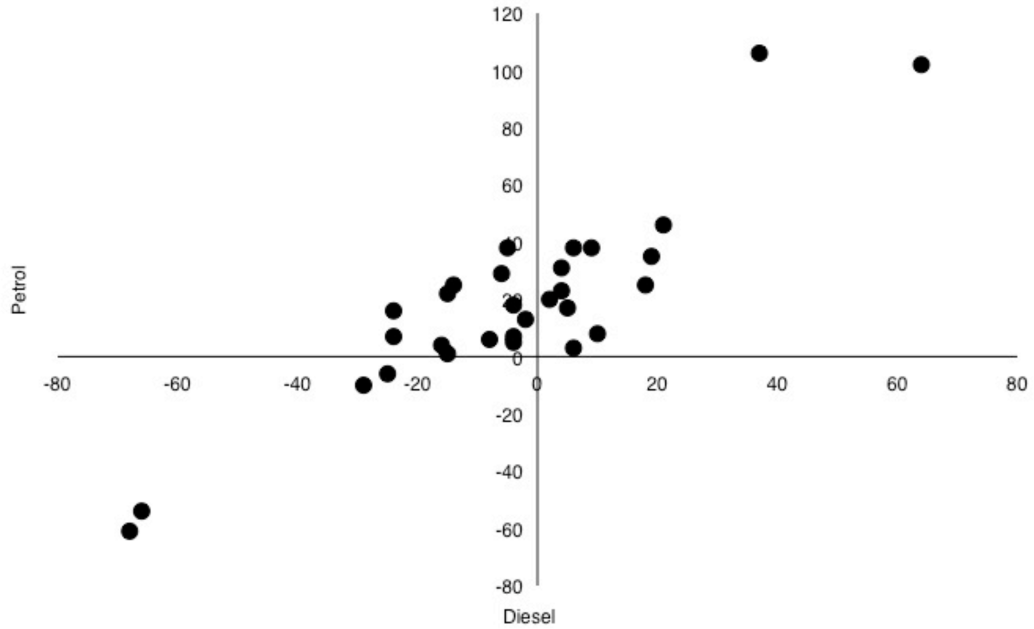
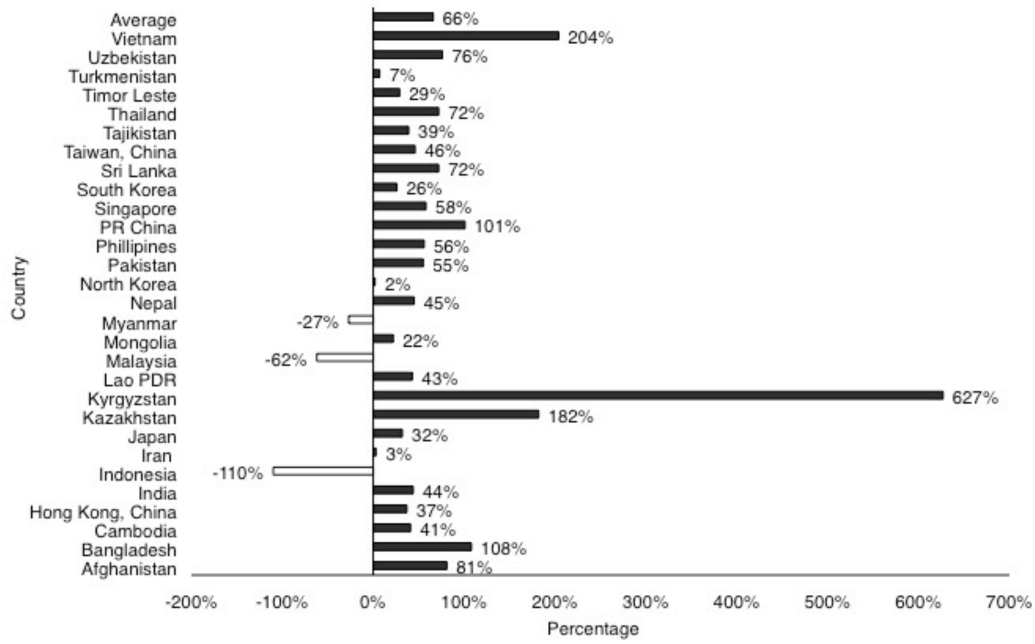
Figure 3. *Taxes and subsidies for diesel and petrol fuel in developing Asia (2006 US dollars)*



Source: Metschies et al, 2005; Metschies & Metschies, 2007; ICCT analysis

Figure 4. Percentage of petrol tax revenue lost in developing Asia



Source: Metschies et al, 2005; Metschies & Metschies, 2007; ICCT analysis

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EU style light-duty dieselisation (i.e. 50% of on-road petrol consumption offset by diesel used in engines with an average improvement in fuel economy of 30%), would on average result in the loss of approximately two-thirds of government revenues generated by the current structure of petrol taxation in Asia.[8] Revenue losses would be particularly large in developing countries: 44% in India, 56% in the Philippines, 72% in Thailand, 108% in Bangladesh and more than double baseline petrol revenues in Vietnam. While fuel taxes may not currently account for very large percentages of overall revenues in many of these countries, cash-strapped governments in developing Asia aspiring to first-world economies may find themselves having to sacrifice key development goals should light-duty dieselisation begin to reduce fuel tax revenues.

[a] An integrated policy strategy to manage light-duty dieselisation

The above analysis shows that a new policy framework is needed to maximise co-benefits and avoid trade-offs associated with the increased use of diesel engines in light-duty applications in developing Asia. In this section, we describe three core principles for designing an integrated policy to maximise the environmental and developmental benefits of light-duty dieselisation: first, a single set of fuel-neutral conventional pollutant emission standards for passenger vehicles; second, fuel efficiency standards set either as a single corporate average or based upon vehicle size; third, taxing transport fuels based upon their carbon content.

[b] Stringent fuel neutral passenger vehicle emission standards

Climate, public health and development goals all point to the need for a single set of conventional pollutant emission standards imposed on all passenger vehicles regardless of fuel type. Unified targets establish a level technology playing field and

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prevent policy makers from favouring certain control strategies by handicapping the environmental performance of a given technology. Moreover, requiring that light-duty diesels meet petrol-level targets for particulate and NOx emissions will maximise the climates benefit of light-duty diesels while minimising the public health and development risks of exposure to exhaust particulate and ground-level ozone formed by NOx precursors.

While the precise pace of change will vary from country to country, ultimately regulatory requirements for diesel passenger vehicles in developing Asia are likely to converge with US, EU, or Japanese standards. To date only the United States requires that petrol and diesel passenger vehicles meet common emission targets, in the form of US EPA's Tier 2 emission standards.[9] Both Europe and Japan, while requiring that diesel passenger vehicles meet near zero particulate emission standards from 2009 (0.005 g/km for most passenger vehicles), will continue to impose relaxed NOx requirements on light-duty diesels for the foreseeable future (Dieselnet, CEC 2005). Weaker diesel NOx standards leave open the possibility that public health could suffer as diesel engines come into greater use in countries adopting European or Japanese-style regulations, an outcome that violates the goal of maximising transportation co-benefits.[10] Consequently, the stringent fuel neutral principles of US Tier 2 emission standards for passenger vehicles should be considered for adoption by developing countries worldwide, recognising that different countries are likely to pursue different paths toward fuel neutrality.[11]

In addition to engine improvements, US Tier 2 or equivalent emission standards will require the use of state-of-the-art, commercially available diesel emission control technologies, most notably wall-flow particulate filters, NOx after-treatment (either selective catalytic reduction or lean-NOx traps) and diesel fuel with a sulphur content of less than 15 parts per million, which serves as a key enabling technology for diesel after-treatment.[12] Luckily, developing countries in Asia can

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benefit from technologies and practices perfected in the US, EU and Japan, where automakers developed these technologies in response to technology-forcing regulatory requirements. Where possible, developing countries should skip over interim standards and technologies entirely in favour of "leapfrogging" to the most stringent standards to protect human health and the environment.

Though distinct from the after-treatment control technologies that are the primary focus of this paper, lower-sulphur diesel fuel deserves separate mention as a key technology to avoid the dis-benefits of uncontrolled diesel passenger vehicles. Fuel quality has significant direct and indirect consequences for diesel vehicle emissions. Reducing sulphur in diesel reduces direct emissions of sulphate particles as well as emissions of sulphur dioxide (SO_2), which can convert into particles and acids in the atmosphere. In addition, sulphur is a catalyst poison. All advanced after-treatment control technologies perform better with the use of lower sulphur fuel, ideally with sulphur levels of 15 ppm or less. Because low-sulphur fuels are a prerequisite for many advanced after-treatment technologies for diesel engines, fuel sulphur standards have preceded emissions standards for heavy-duty vehicles in the EU, Japan and the United States, and should therefore be considered as part of an integrated strategy to cope with light-duty dieselisation.[13]

The climate benefit of standards requiring diesel particulate after-treatment technologies is best shown by comparing the CO_2-equivalent emissions of diesel passenger vehicles sold with and without particulate filters in Europe.[14] From the KBA test data, we identified 52 identical matched pairs with and without a particulate filter representing twenty-nine vehicle models offered by fifteen manufacturers. A summary of vehicle characteristics for the study population is given in Table 5. Results of the analysis are provided in Table 6.

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Table 5. *KBA database vehicle characteristics*

Manufacturers	Vehicle models	Matched pairs	Engine size (cm^3)	Engine power (kW)	Max speed (km/h)	Inertia mass (kg)
15	29	52	2120	99	186	1842

Source: Kraftfahrt Bundesamt, 2007; ICCT analysis

Table 6. Effect of the diesel particulate filter on emissions of new light-duty diesels in the 2007 European fleet

			Change in CO2-equivalent emissions	
	CO2 (g/km)	PM (g/km)	GWP20	GWP100
with filter	0.50%	-87%	-13.9 (-7.6 to - 21.5)	-4.2 (-1.7 to - 7.5)

Kraftfahrt Bundesamt, 2007; ICCT analysis

Vehicles with a filter produced on average 186 g/km CO_2, a share 0.5 percent greater than vehicles without a filter, although only 30 percent of the sample showed any change in emissions.[15] In contrast, average particulate emissions were reduced to . 004 g/km, an 87 percent reduction with the application of a filter. On a GWP20-basis, diesel vehicles with filters reduced emissions 13.9% (range 7.6% to 21.5%) compared to diesel vehicles without filters. They reduced emissions 4.2% (range 1.7% to 7.5%) on a GWP100-basis.[16]

[b] Single corporate average or footprint-based efficiency standards

The second core principle defining an integrated policy to maximise co-benefits from light-duty dieselisation is that passenger vehicle efficiency or GHG emission targets should be set based upon either a pure corporate average approach or upon vehicle footprint, rather than weight. As a general rule passenger vehicle efficiency is typically regulated on one of three bases: as a pure corporate average standard, which requires all automakers to meet a common efficiency target regardless of what size and weight of vehicles they sell; as a size or footprint-based standard, which sets individual targets based on the area bounded by the tires of a vehicle and establishes more lenient standards for large vehicles on an absolute (i.e.

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g/km) basis; or a weight-based standard, which establishes differential targets based upon vehicle weight.[17]

The choice of standard basis is an important one, holding implications for a variety of policy and economic goals, including industry competition, the magnitude and distribution of compliance costs among manufacturers, and the ability of manufacturers to market various size vehicles without reference to government regulation. For our analysis, we are concerned primarily with how the efficiency targets assigned by a given standard basis respond to light-duty dieselisation. The analysis showed that some of the efficiency improvements offered by diesel passenger vehicles are likely to be foregone under weight-based standards as vehicle mass increases when automakers add heavy diesel engines and make other design changes to sell high-performance diesel passenger vehicles.

Single corporate average and footprint-based standards establish performance targets resistant to changes in fuel type, vehicle weight and engine size, as shown in Table 7. The left hand columns of that table show the size (measured as pan area), fuel type, curb weight and engine size of a single German passenger vehicle model sold in various configurations. The rightmost three columns of the table show the emission targets, in terms of grams of CO_2 per kilometre, that would be assigned each configuration under a single corporate standard, a footprint-based standard and a weight-based standard, each imposing upon the European fleet wide target of 130 g/km.[18]

Table 7. *Targets of various fuel efficiency standards*

Vehicle types						2012 EU target (g/km)		
Conf	Pan Area (m^2)	Fuel	Curb weight (kg)	Engine size (L)	2006 Emissions (g CO_2/km)	Single corporate	Footprint	Weight
A	9.58	Petrol	1805	3.0	241	130	156	154
B			1895	4.0	267			158
C			1910	4.8	271			158
E		Diesel	2040	4.4	239			164

Source: BMW, 2007. Columns 7-9 based on ICCT analysis

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Table 7 shows that a pure corporate average (set at 130 g/km by definition for all vehicles) and footprint-based standards (156 g/km) impose identical targets to vehicles of a common size regardless of engine size or fuel, while a weight-based standard assigns weaker targets to vehicles with large and diesel-powered engines.[19]

Assuming that manufacturers market vehicles with size and performance that in aggregate causes them to exactly comply with fuel efficiency and/or GHG standards, standards set based upon vehicle weight will provide less fleet-wide energy conservation or emissions reductions as the market share of diesel passenger vehicles increases. No similar degradation of targets occurs under corporate average or footprint-based standards, both of which require that vehicles meet the same targets even as they increase in performance and/or weight.

Light-duty fuel efficiency standards in Asia set based upon either a pure corporate average approach or by reference to vehicle size will therefore maximise the environmental benefits of diesel passenger vehicles. Moving away from weight-based standards will also provide additional ancillary benefits, including a strong incentive to improve vehicle efficiency through the use of lightweight materials, minimising total industry compliance costs, and fully rewarding today's efficient manufacturers.[20] Where weight-based standards must be used, up-weighting due to dieselisation or increased engine size can be addressed through supportive fiscal measures such as taxes or registration fees set as a function of vehicle weight or engine displacement. In particular, the experience of Japan, where such taxes seem to have acted as a disincentive for up-weighting, may be particularly useful in this regard.[21]

[b] Taxation of transport fuels by carbon content

The third and final principle for maximising co-benefits from dieselisation is that fuels for passenger vehicles should be taxed in proportion to their carbon

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content, set at a level consistent with meeting developmental goals. Asian governments tend to subsidise diesel fuel, while imposing a modest tax on petrol to generate tax revenue for road construction and maintenance. The decision to underprice diesel, while originally predicated on the goal of protecting economically important industries, undermines both environment and developmental goals in the face of light-duty dieselisation, as illustrated by this analysis. As much as two-thirds of petrol tax revenues in Asia could be lost under European-style dieselisation.

Passenger vehicle fuels should therefore be taxed in proportion to their carbon content, set at a level consistent with meeting developmental goals. Under such a system, governments would tax diesel fuel at levels approximately 15% above that of conventional petrol. Doing so would safeguard 85% or more of the revenue losses associated with light-duty dieselisation, help establish a consistent carbon price for on-road transportation and would internalise some of the social costs associated with the use of diesel fuel.[22] Governments might also consider higher taxation of diesel fuel to internalise the social costs associated with increased local air pollution from light-duty diesels, although direct action on emission standards may be preferable given the difficulty of estimating the proper level of taxation over the entire fleet. Relatively higher taxation of diesel fuel may also help avoid the so-called "rebound effect" whereby vehicle use increases from reduced expenditures on fuel.

Where necessary, additional steps can be taken to mitigate the effects of a diesel price increase on the agricultural, fishing, construction and trucking sectors through two-tier pricing, or by fuel tax rebates such as those currently in place in Japan. Where adopted, fuel tax rebates should be administered so as to not provide an opportunity for regulatory capture.[23]

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[a] Conclusions

In this paper, we have outlined the environmental and developmental trade offs – or climate dis-benefits – that are likely to accompany light-duty dieselisation given current policies in developing Asia. These dis-benefits arise when emission control and fuel taxation policies historically used to favour diesel engines in agricultural, fishing, construction and trucking applications spill over into the light-duty sector, where diesels are the dirtiest of several competing technologies. To prevent or minimise these dis-benefits, we recommend that policy makers proactively adopt an integrated emissions control policy consisting of fuel-neutral emission and efficiency standards and fuel taxes based upon carbon content.

Successful implementation of these policies will require strong governance and institutions to design and enforce regulations well. Challenges with existing regulations, such as manufacturer compliance with emission standards, have arisen in developing Asia and will require careful vigilance. Lessons from Japan, the United States and Europe can teach how to successfully regulate diesel vehicles. Countries in developing Asia might consider bilateral and multi-lateral partnerships to gain access to technical resources.

While light-duty dieselisation has been the primary focus of this paper, an integrated policy to minimise climate dis-benefits from light-duty dieselisation will also support the commercialisation and adoption of low or even zero carbon technologies for passenger vehicle transport in developing Asia. While a number of challenging policy questions (e.g. emissions test cycles, characterisation of upstream emissions, etc.) still need to be answered, a robust, competitive market for plug-in hybrid, battery electric and fuel cell drive trains is more likely to develop if fuel-neutral emissions standards, efficiency standards and fuel taxation are put in place today (Lloyd 2008).

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[a] Notes

1 While population statistics for light-duty diesels in Asia can be difficult to obtain, work by India's Centre for Science and Environment suggests that the number of diesel cars in-use in Delhi increased more than 250% between 1999 and 2006. (Centre for Science and Environment, undated).

2 Our analysis excluded electric drive, liquefied natural gas and compressed natural gas vehicles. Vehicles with direct injection engines were included.

3 Based on data published in the IPCC Fourth Assessment Report (Forster et al, 2007) and our own calculations (International Council on Clean Transportation, 2009) the 100-year GWP of black carbon is 460 (range 138 to 920) and the 20-year GWP is 1600 (range 480 to 3200). Organic carbon is co-emitted with black carbon and reflects light, causeing negative radiative forcing, so its GWP values are negative. This was accounted for in all GWP calculations. We assumed organic carbon constituted 90 percent of PM from vehicles with a filter and 30 percent of PM from vehicles without one (Ayala, A. Personal communication, 17 Oct). Our estimate of the 100-year GWP for organic carbon is -69 (range -21 to -138) and the 20-year

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GWP is -240 (range -72 to -480) (International Council on Clean Transportation, 2009).

4 Since CO_2 emissions are relatively constant per litre, fuel efficiency is directly related to emissions of CO_2 per kilometre.

5 Since particulate emissions data were not available for petrol vehicles, we cannot make a comparison, although properly operating petrol vehicles typically produce extremely low particulate emissions.

6 We report our main findings using the 20-year GWP as it is consistent with our focus on co-benefits, particularly public health, and since short-lived forcers are best suited for short-term policy targets.

7 For example, in India Euro 3 standards for light-duty diesels will not be enforced nation wide until April 2010. Also in 2010, Euro 4 standards will take effect in the Delhi Capital Region and in 10 other large cities (DieselNet 2004).

8 The three countries that heavily subsidise both petrol and diesel or that tax diesel fuel more heavily than petrol (Myanmar, Malaysia and Indonesia) and that would therefore increase revenues through dieselisation are outlined in grey.

9 On average, when fully phased in Tier 2 standards will limit NOx and PM emissions to 0.044 g/km and approximately 0.0063 g/km, respectively, over useful vehicle lifetimes (i.e. 192,000 km and 10 to 11 years, whichever comes first, depending on GVW) (Dieselnet 2008).

10 Along with a direct increase in NOx emissions, weak NOx standards can delay the introduction of diesel particulate filters by allowing manufacturers to meet PM emissions by managing the NOx/PM trade off rather than by introducing particulate filters, which provide maximum protection from ultra fine particulate. Where fuel neutral standards are not possible, governments might consider the European approach, which has adopted number-based standards to drive filter adoption for

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both light and heavy-duty diesel vehicles. For further information, see International Council on Clean Transportation, 2005.

11 Hong Kong, for example, has adopted California's standards for diesel cars.

12 For further information about emission control strategies and technologies for heavy-duty vehicles, see Walsh et al, 2007.

13 For more detail on the importance of reducing sulphur in transportation fuels, see Blumberg et al, 2003.

14 Avoiding increased NOx emissions due to dieselisation is also likely to provide regional climate benefits by inhibiting ground-level ozone formation. Since those benefits are highly dependent on confounding variables such as atmospheric conditions etc, we focus our discussion here on PM alone.

15 This change was both positive and negative, although on the whole the trend was negative. Fourteen of the sixteen vehicle pairs showing a change experienced a penalty that ranged between 2 and 9 g/km (0.7-4.5%). The remaining two vehicle pairs experienced a benefit of between 3 and 6 g/km (2-4.1%).

16 The GWP20 puts greater weight on short-lived emissions, while the GWP100 puts greater weight on long-lived emissions. The policy goal should be taken into account to determine which time horizon is appropriate, so that short-term policy goals like mitigating climate change above a certain level within twenty years utilise the GWP20 and policy goals to mitigate impacts within 100 years utilise the GWP100

17 The targets assigned to individual automakers under corporate average standards can vary somewhat due to differences in the proportion of their vehicles sold in different vehicle classes, an approach taken under the United States' CAFE standards. Since class-based corporate average standards are not affected by dieselisation-related up-weighting within a vehicle class, such systems are not discussed further here.

18 Attribute-based standards "control" for vehicle efficiency differences due to either size or weight, and by definition require smaller reductions from larger or heavier

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vehicles than for smaller or lighter vehicles compared to a pure corporate average standard of the same stringency. The large size and weights of the vehicles shown in Table 7 relative to the overall European average explains why both the footprint and weight-based targets require smaller emissions reductions than under a pure corporate average approach.

19 Note that the European weight-based proposal, shown in the far right column of Table 7, was set with a relatively flat slope to dampen the potential effects of up-weighting. As a result, the 10 g/km difference in GHG emission target stringency shown between petrol and diesel versions with identical similar baseline 2006 emissions (A and E) would be larger under weight-based standards with a steeper slope, such as those in place in China and Japan.

20 These advantages of corporate average and footprint-based standards will be described further in a future paper on design principles for passenger vehicle fuel efficiency and GHG standards from the ICCT.

21 For further information about Japan's use of fiscal incentives to promote passenger vehicle efficiency, see the upcoming ICCT report entitled "Fiscal Policies for Passenger Vehicle CO_2 Reduction: A Global Review." Expected publication date: fall 2009.

22 The remaining 15% of revenue lost would be attributable to a lower volume of fuel sales due to the efficiency advantages of diesel engines.

23 For details about how diesel tax rebates to the trucking industry has aided regulatory capture in Japan, see Rutherford 2006, p. 75-76.

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